# Effects site conditions on industrial fiber plantations of *Larix olgensis*

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**Abstract**: Plot sampling was conducted in the second cultivation areas of *Larix olgensis* in Heilongjiang Province, China. By analyzing plot investigation data, wood properties, and kraft pulps of 840 plots and 248 sample trees in industrial plantations of *L. olgensis* on different sites, we examined the growth process of *L. olgensis* industrial plantation with suitable structure, the wood fiber feature, chemical composition, physical performance and pulp characteristics. It is suggested that site conditions have major effects on plantation growth, fiber contains, fiber length, rate between fiber length and fiber width, pulping rate and pulp physics intensity. The best site for *L. olgensis* industrial plantation growth is site class I and site class II, which are on lower locations. Site condition has an obvious influence on the wood characteristics. Within the range of site conditions and stand densities studied, the worse the site condition, the less the fiber contains, the shorter the fiber length, and the more the 1 % NaOH extraction. This kind of relationship becomes more obvious as stand age increases. However, the influence of site condition on pulping rate and pulp physics intensity is not obvious. The result provides theoretical base for cultivation of industrial fiber plantation of *L. olgensis*.

**Keywords:** *Larix olgensis*; Industrial plantation; Site regulation. Site index; Site conditions
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## Introduction

*Larix olgensis* is an important plantation tree species in northeast China. It has the excellent features such as fast growth, wide distribution, and sustainable wood intensity. The timber can be used in building, boat making, bridge and other engineering. It is also an important fiber tree species. Extensive researches have been conducted on cultivation techniques of (Zhu *et al*. 2005; Li *et al*. 1998; Li *et al*. 1994; Sun *et al*. 1998) and plantation sites (Hu 2001; Liu *et al*. 1998; Liao *et al*. 1997) of *L. olgensis* industrial fiber plantations in China., The relationship between site conditions and plantation growth were well reported (Sun 1999; Zhao *et al*. 2004; Ma *et al*. 2001; Xun *et al*. 1990; Li *et al*. 1996; Zhang *et al*. 1999). However, very few studies were about the site regulation techniques with the manner of considering both plantation growth and wood features. For industrial fiber plantation cultivation, more attention needs to be paid to its growth and wood features. In this paper, we studied the site regulating techniques of industrial fiber plantation of *L. olgensis* with the manner of considering the growth of plantation and wood features.

## Study area and methods

The study was conducted in the second cultivation areas of *L. olgensis* in Heilongjiang Province, China. The sample plots covered 17 counties: Baoqing, Bayan, Ninan, Dongning, Linkou, Hailin, Shangzhi, Yanshou, Tonghe, Yilan, Fangzheng, Hailun, Jixi, Jidong, Mishan, Tiangyuan, and Wuchang, and 6 cities: Tieli, Yichun, Hegang, Jiamusi, Suihua, and Shuangyashan. Growing-season precipitation is greater than 500 mm, and above-10°C accumulated temperature per year is 2 301–2 800°C. Above-10°C period is 131–150 days. Relative humidity is 0.6–0.9 (Forestry Ministry 1987).

Base on observations on 840 plots and 248 sample trees in industrial plantations of *L. olgensis* on different sites, we analyzed the suitable structure with the Weibull distribution model:

$$f(x) = (c/b) \times (((x-a)/b)^{(c-1)}) \times \exp(-((x-a)/b)^c) \tag{1}$$

where $a$ is the location parameter, $b$ the scale parameter, and $c$ the shape parameter. Parameters $a$, $b$ and $c$ were determined with the index table method (Arbuxinxing 1986). This model was used to simulate plantation growth process, and then to determine the suitable sites for industrial plantation growth of *L. olgensis*.

The average trees were sampled in industrial fiber plantations of *L. olgensis* by different ages, site conditions, and stand densities. Fiber compositions, fiber length, width and inorganic additives as well as pulping rate and physical properties of the pulps were measured by means of Kajaani FS-100 fiber analyzer, chemical analyses manner and kraft pulping manner (Table 1).

**Table 1. Wood feature analysis of industrial fiber plantation of *L. olgensis***

| No. | Stand age (a) | Site class | Stand density (Trees·hm$^{-2}$) | Water content (%) | Wood density (g·cm$^{-3}$) |
|---|---|---|---|---|---|
| 1 | 20 | I | 1600 | 37.21 | 0.49 |
| 2 | 20 | I | 2300 | 37.66 | 0.46 |
| 3 | 20 | III | 1500 | 43.35 | 0.46 |
| 4 | 20 | III | 2040 | 35.63 | 0.44 |
| 5 | 25 | II | 1400 | 37.21 | 0.51 |
| 6 | 25 | II | 2220 | 45.13 | 0.49 |
| 7 | 25 | IV | 1200 | 42.15 | 0.52 |
| 8 | 25 | IV | 1600 | 37.88 | 0.53 |

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## Result

### Structure and growth of *L. olgensis* plantations

We developed equations between Weibull index and average diameter with plot data of industrial fiber plantation of *L. olgensis*.

The resultant models are as follows:

$$\ln D_{min}=-1.294762633+1.103411027\ln AD \quad (R=0.9852) \tag{2}$$

$$\ln a=-1.8726204+1.279273774\ln AD \quad (R=0.9849) \tag{3}$$

$$1/b=0.0015197+1.10577282436/AD \quad (R=0.9849) \tag{4}$$

$$1/c=0.2219462125+1.23402502/AD \quad (R=0.9840) \tag{5}$$

Where, $D_{min}$ is the smallest diameter, $AD$ is the average diameter. We then obtained relevant diameter distribution of *L. olgensis* plantation with fixed average diameter according to the Weibull distribution model and stand management density table (Liu 1987).

On the basis of the volume formula of Larch plantations ($V$=0.000192619$D^{2.25034}$) (Zhong & Wang 1987), and diameter distribution structure, we obtain the relationships among $AD$, stand density and stand volume, and then get the stand volume growth process according to these relationships and the relationships between diameter and age (Table 2).

**Table2. Growth process of *Larix olgensis* industrial fiber plantation (different slope location)**

| Average Diameter (cm) | Density (Trees·hm$^{-2}$) | Volume (m$^3$·hm$^{-2}$) | Upper location | | Middle location | | Lower location | |
|---|---|---|---|---|---|---|---|---|
| | | | Age (a) | Average growth (m$^3$·hm$^{-2}$·a$^{-1}$) | Age (a) | Average growth (m$^3$·hm$^{-2}$·a$^{-1}$) | Age (a) | Average growth (m$^3$·hm$^{-2}$·a$^{-1}$) |
| 6 | 4025 | 60.9230 | 16.19 | 3.7626 | 13.83 | 4.4064 | 12.60 | 4.8364 |
| 7 | 3446 | 73.7565 | 17.38 | 4.2446 | 14.86 | 4.9628 | 13.57 | 5.4363 |
| 8 | 3021 | 87.6280 | 18.65 | 4.6991 | 15.98 | 5.4852 | 14.61 | 5.9966 |
| 9 | 2685 | 101.6695 | 20.01 | 5.0804 | 17.17 | 5.9205 | 15.74 | 6.4597 |
| 10 | 2421 | 116.4968 | 21.48 | 5.4244 | 18.46 | 6.3111 | 16.95 | 6.8722 |
| 11 | 2202 | 131.5806 | 23.05 | 5.7090 | 19.84 | 6.6314 | 18.26 | 7.2067 |
| 12 | 2023 | 147.5410 | 24.73 | 5.9650 | 21.33 | 6.9175 | 19.66 | 7.5027 |
| 13 | 1867 | 163.1513 | 26.54 | 6.1464 | 22.93 | 7.1162 | 21.18 | 7.7030 |
| 14 | 1738 | 180.2541 | 28.49 | 6.3276 | 24.64 | 7.3142 | 22.81 | 7.9016 |
| 15 | 1623 | 196.0600 | 30.57 | 6.4132 | 26.49 | 7.4011 | 24.57 | 7.9796 |
| 16 | 1527 | 213.4827 | 32.81 | 6.5070 | 28.48 | 7.4971 | 26.46 | 8.0670 |
| 17 | 1433 | 229.0107 | 35.21 | 6.5044 | 30.61 | 7.4818 | 28.50 | 8.0347 |
| 18 | 1357 | 247.9729 | 37.78 | 6.5627 | 32.90 | 7.5366 | 30.70 | 8.0775 |
| 19 | 1287 | 264.3426 | 40.55 | 6.5190 | 35.37 | 7.4742 | 33.06 | 7.9947 |
| 20 | 1224 | 282.2895 | 43.52 | 6.4869 | 38.02 | 7.4253 | 35.61 | 7.9267 |
| 21 | 1165 | 297.8627 | 46.70 | 6.3781 | 40.86 | 7.2888 | 38.36 | 7.7656 |
| 22 | 1115 | 317.9649 | 50.12 | 6.3443 | 43.93 | 7.2384 | 41.31 | 7.6966 |

Based on the site class standard and the stand growth equation (Zhong & Wang 1987), the growth process of *L. olgensis* industrial plantations under five site-class conditions from Weibull distribution model is obtained by mean of stand density table (Table 3).

### Suitable sites for growth of *L. olgensis* plantations

*L. olgensis* industrial plantations had the highest growth rate in lower locations of mountains and the lowest growth rate in upper locations of mountains (Table 2). Increment growth exceeded fast-growth stand standard before the stand age of 25 in lower locations. All the growth of *L. olgensis* industrial plantations is lower than the fast-growth stand standard in the upper locations and middle locations (Forestry Ministry 1987). Thus, the lower location is the best site for the growth of *L. olgensis* industrial plantation.

Stand growth had clear relationships with site index values (Table 3). The measured values of diameter (D), height (H) and volume (V) of the stand were higher than those of high yield standard before stand age of 40 under site class I, while for site class II, these measured values of the stand were higher than those of high yield standard before stand age of 25. Under site class III, volume of the stand was bigger than that of high yield standard before stand age of 15, and for site class IV, the volume of the stand was bigger than that of high yield standard before stand age of 10. Under site class V, the measured values of diameter, height and volume of the stand are lower than those of high yield standard (Forestry Ministry 1987). These data suggest that the most suitable site condition for *L. olgensis* industrial plantations growth is site class I and site class II.

### Relationship between wood characteristics and site condition

Site condition has direct impact on wood feature. In the study ranges of site condition and stand density, the worse the site condition, the less the fiber contains, the shorter the fiber length, and the more the 1% NaOH extraction. This phenomenon takes on an increase trend with age increase, but the effects of site conditions on pulping rate and pulp physical performance are not obvious (Table 4).

## Conclusion

The diameter structure of *L. olgensis* industrial plantations can be expressed by Weibull distribution. The distribution index can

be calculated by stand average diameter. The growth processes of *L. olgensis* industrial plantations are different under different site conditions. The best site condition is class I and class II on lower locations. The worst site condition is class V on upper locations. Class III and class IV on middle locations are the middle site conditions. Site conditions have the direct influences on the wood characteristics. Within investigated site conditions and stand densities, the results showed that the worse the site condition, the less the fiber contains, the shorter the fiber length, and the more the 1 % NaOH extraction. This kind of relationship becomes more obvious as stand age increases. However, the effects of site conditions on pulping rate and pulp physics intensity are not obvious. From the point of plantation growth and wood characteristics, we should cultivate the industrial fiber plantations of *L. olgensis* at the site of class I and class II on low locations.

**Table3. Growth process of *Larix olgensis* industrial fiber plantation (different site class)**

| Site index | Age (a) | Diameter (cm) | Height (m) | Density (Trees·hm$^{-2}$) | Volume (m$^3$·hm$^{-2}$) | Average growth (m$^3$·hm$^{-2}$·a$^{-1}$) |
|---|---|---|---|---|---|---|
| I | 10 | 7.90 | 7.78 | 3061 | 86.2215 | 8.6222 |
| | 15 | 11.19 | 11.77 | 2167 | 134.8518 | 8.9901 |
| | 20 | 14.32 | 14.85 | 1697 | 184.6898 | 9.2345 |
| | 25 | 17.28 | 17.12 | 1413 | 235.1517 | 9.4061 |
| | 30 | 20.07 | 18.68 | 1220 | 283.2415 | 9.4414 |
| | 35 | 22.69 | 19.64 | 1080 | 329.4114 | 9.4118 |
| | 40 | 25.15 | 20.09 | 977 | 374.6628 | 9.3666 |
| II | 10 | 5.63 | 6.70 | 4289 | 56.3726 | 5.6373 |
| | 15 | 9.29 | 10.55 | 2603 | 105.9994 | 7.0666 |
| | 20 | 12.55 | 13.48 | 1937 | 156.3387 | 7.8169 |
| | 25 | 15.40 | 15.64 | 1580 | 202.4737 | 8.0989 |
| | 30 | 17.84 | 17.21 | 1366 | 243.8053 | 8.1268 |
| | 35 | 19.88 | 18.31 | 1229 | 279.8931 | 7.9969 |
| | 40 | 21.52 | 19.07 | 1141 | 309.7840 | 7.7446 |
| III | 10 | 4.52 | 5.68 | 5323 | 43.3177 | 4.3318 |
| | 15 | 7.66 | 9.17 | 3155 | 82.8223 | 5.5215 |
| | 20 | 10.53 | 11.91 | 2300 | 124.5014 | 6.2251 |
| | 25 | 13.16 | 14.01 | 1847 | 165.6171 | 6.6247 |
| | 30 | 15.52 | 15.58 | 1570 | 205.3175 | 6.8439 |
| | 35 | 17.63 | 16.72 | 1385 | 240.7176 | 6.8776 |
| | 40 | 19.48 | 17.52 | 1256 | 272.4244 | 6.8106 |
| IV | 10 | 3.15 | 4.56 | 7632 | 29.6997 | 2.9700 |
| | 15 | 6.66 | 7.88 | 3622 | 69.3386 | 4.6226 |
| | 20 | 9.64 | 10.51 | 2513 | 111.0796 | 5.5540 |
| | 25 | 12.06 | 12.51 | 2012 | 148.3119 | 5.9325 |
| | 30 | 13.95 | 13.99 | 1743 | 178.7188 | 5.9573 |
| | 35 | 15.30 | 15.00 | 1592 | 200.9492 | 5.7414 |
| | 40 | 16.10 | 15.58 | 1514 | 214.4678 | 5.3617 |
| V | 10 | 2.26 | 3.44 | 1061 | 23.3669 | 2.3367 |
| | 15 | 5.55 | 6.21 | 4341 | 55.4861 | 3.6991 |
| | 20 | 8.31 | 8.53 | 2908 | 92.0110 | 4.6006 |
| | 25 | 10.54 | 10.41 | 2298 | 124.8811 | 4.9952 |
| | 30 | 12.24 | 11.84 | 1983 | 150.8759 | 5.0292 |
| | 35 | 13.42 | 12.88 | 1812 | 169.9149 | 4.8547 |
| | 40 | 14.06 | 13.37 | 1730 | 180.5799 | 4.5145 |

**Table 4. Wood characteristics of different site conditions**

| Age (a) | Site class | Fiber Contains (%) | Fiber length ( mm) | Length/width | Pulping rate (%) | 1%NaOH extraction (%) | Avulsion index (mN·m$^2$/g) |
|---|---|---|---|---|---|---|---|
| 20 | I | 48.32 | 2.60 | 88.0 | 45.48 | 14.38 | 16.75 |
| 20 | III | 47.61 | 2.54 | 85.6 | 45.90 | 14.60 | 19.34 |
| 25 | II | 52.78 | 5.51 | 81.4 | 45.22 | 13.90 | 21.19 |
| 25 | IV | 45.44 | 2.41 | 76.6 | 44.22 | 20.84 | 19.70 |

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